Detection and Monitoring of Very Slow Landslides in Vicinity of an Artificial Reservoir using Advanced Differential SAR Interferometry: A Case Study of Tehri Region, India

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Abstract

Persistent Scatterer Interferometry (PSI) is a novel remote sensing technique for monitoring land deformation on large scale. It is economic and can be used for detection of land surface deformation in the past given that the sensor should have passed over the area. The millimetric precision of the technique makes it very useful. One of its application is monitoring of slow moving landslides. In this study we have focused upon monitoring of slow moving landslides in Tehri region of Uttarakhand state of India. This area is landslide prone. Its susceptibility to landslide has increased due to construction of artificial reservoir in the region. The variation in reservoir drawdown level can be cited as one of the reasons. In this study we have applied Persistent Scatterer Interferometry on the stack of 20 Single Look Complex (SLC) scenes of Envisat satellite of European Space Agency. We have performed time-series analysis for period starting from 12 May 2008 to 26 July 2010. The methodology consists of selection of master image, coregistration of other slave images to master image, calculation of amplitude stability index, generation of reflectivity map. After this 19 interferograms were generated. On basis of this selection of Persistent Scatterers (PS) is done. After that estimation and removal of Atmospheric Phase Screen (APS) was done. In the end calculation of time-series displacement of PSs is performed. From this analysis we are able to identify the spatial location of slow moving landslides. In this study we have identified PSs having nearly 40 mm/year of velocity. Detected areas showing land movement away from the line of sight of satellite, can be found on the rim of reservoir as well as areas 4 kilometres interior, away from the boundary of reservoir. These areas are located near roads and places where anthropogenic interference is there.

Background

- Landslides resulting from water impoundment is one of the geo-hazards that exist in artificial reservoir areas. Research study in such areas (for eg. Three Gorges Region) indicates that many pre-existing landslides have now been mobilized and some stable slopes have become unstable after the impoundment of the reservoir. For monitoring superficial displacement offers a simpler way of studying such land movement.
- Remote Sensing Techniques such as **Persistent Scatterer Interferometry** (PSI) have proven to provide good results. It utilises time-series of SAR data, identifies coherent radar targets known as Persistent Scatterers.

For monitoring the past landslides where ground data availability is scarce, archived SAR satellite data offers a nice alternative. Low cost of these techniques combined with milimeteric precision make them valuable for monitoring and detection of slow moving landslides

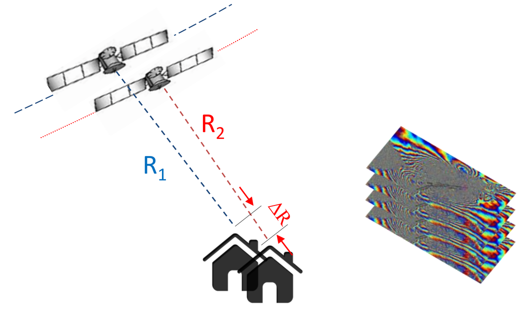

Fig. 1. Persistent Scatterer Interferometry

Research Objective

- To study slow-moving landslides in vicinity of an artificial reservoir of past using archived satellite Radar data with application of Advanced Differential SAR Interferometry (A-DInSAR).

Study Area

- Our study concentrates on area surrounding Tehri Reservoir located in Uttarakhand state of India. It lies in the Lesser Himalaya region which has complex geological environment.
- This 67 kilometers long reservoir was result of construction of Tehri dam at the confluence of Bhagirathi and Bhilangana rivers.
- The Tehri reservoir affects the stability of slopes in the rim area as during peak monsoon saturates the valley slopes. The saturated slopes, post-monsoon along the reservoir often become unstable which results in the form of landslide at number of places.

Fig. 2 Deformation affecting the rim of Tehri reservoir. (Source: www.iirs.gov.in)

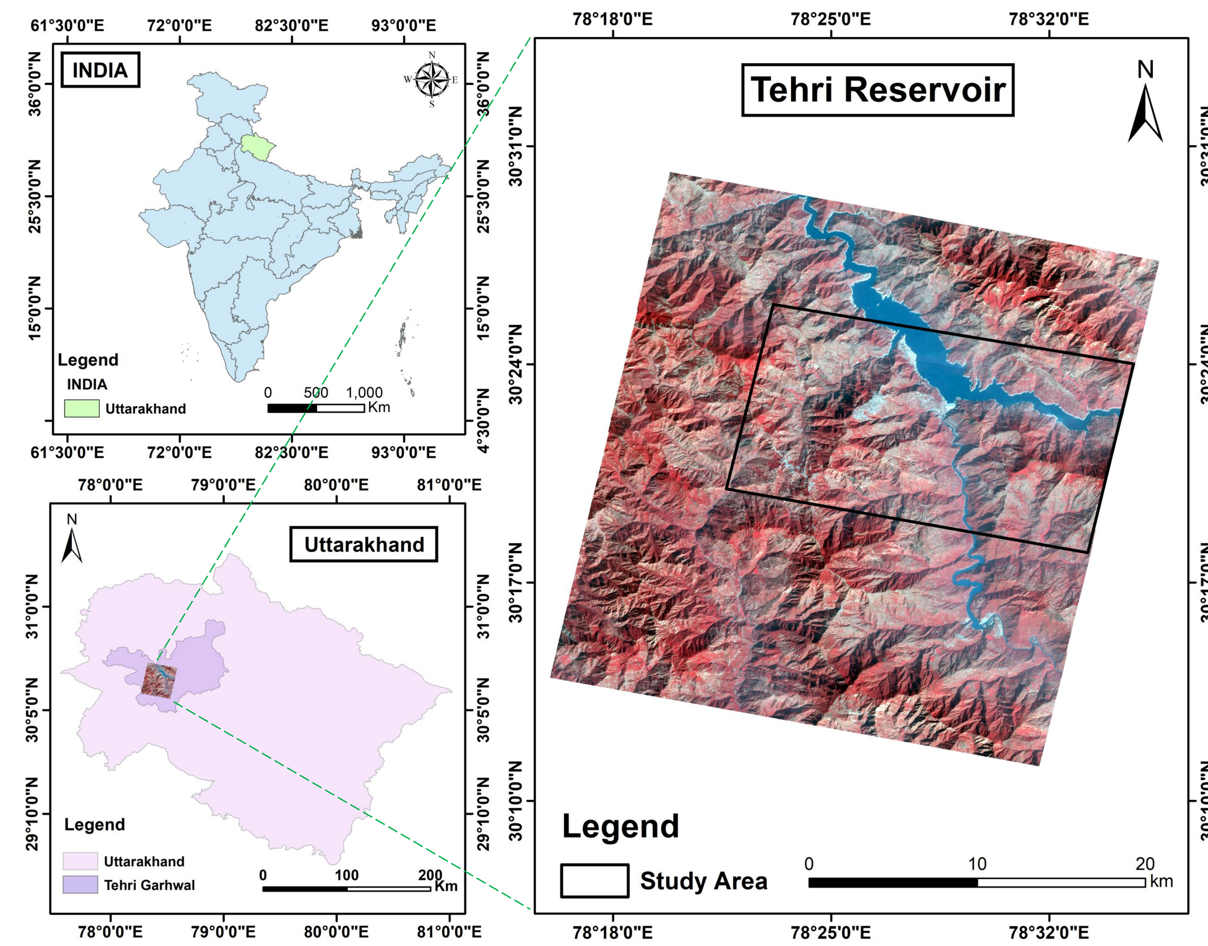

Fig. 3. Location of the study area

Methodology

A Persistent Scatterer Interferometry workflow (Fig 3) has been implemented. This utilizes time-series data for removing the phase induced by atmospheric interaction in the interferometric phase.

Reflectivity map is image where each pixel is the temporal mean of corresponding pixels from all the image in the resampled dataset. It is calculated as follows:

$$m_A = \sum_{i=1}^{n} I_i / n$$

where n is number of images, I is the intensity.

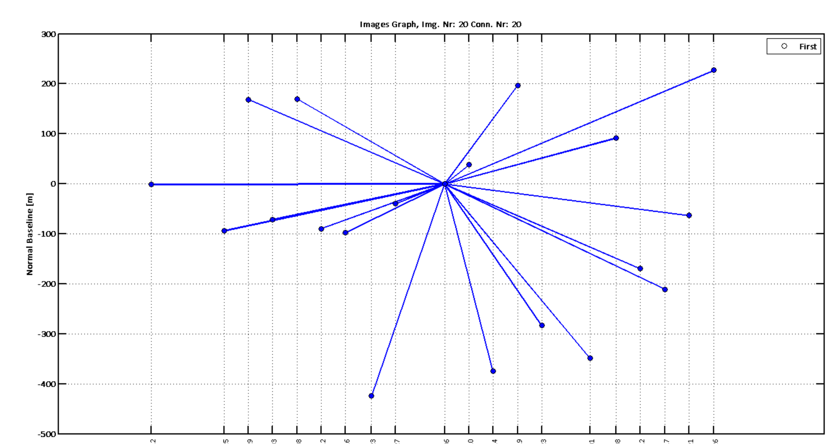

Fig. 4. Star-graph of processed ENVISAT data showing temporal and spatial baselines.

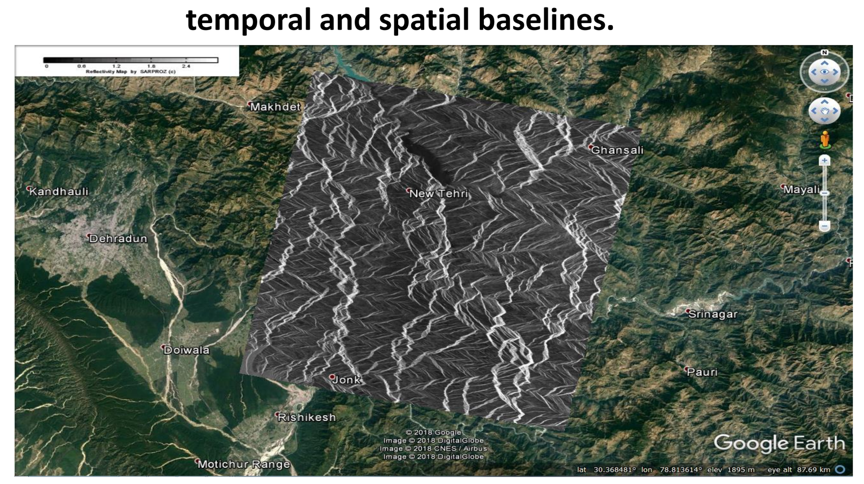

Fig. 5. Reflectivity Map of the area

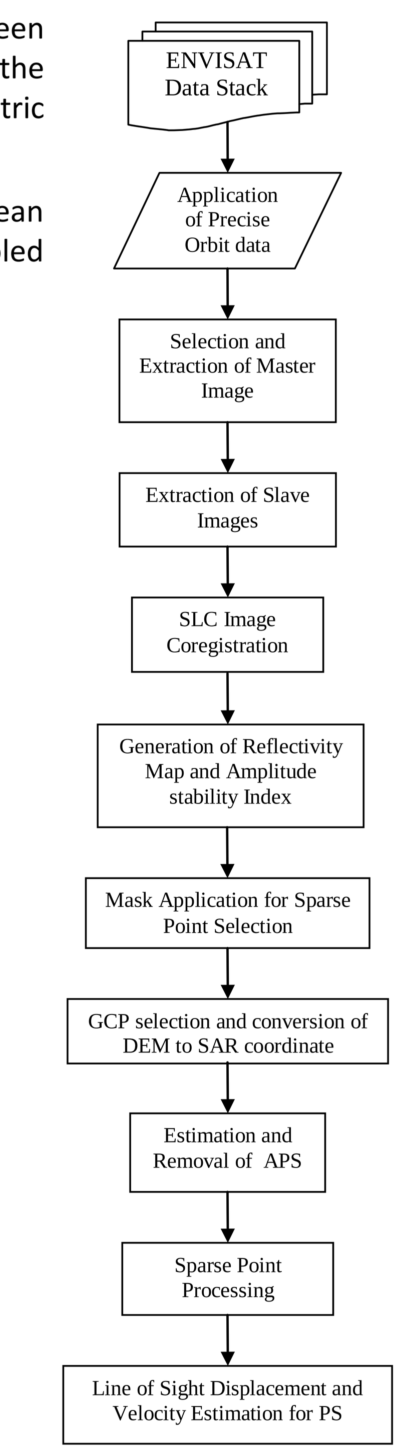

Fig. 6. Methodology Adopted for Processing

Data Used

We have used 20 ENVISAT scenes which is a C-band SAR sensor launched by European Space Agency.

Table 1. ENVISAT Data Specification

Date (YYYY-MM-DD)	Polarization	Spatial Baseline (m)	Temporal Baseline (days)	Doppler Centroid (Hz/PRF)
20080512	VV	-1.43615	-420	0.097206
20080825	VV	-94.3464	-315	0.102554
20080929	VV	168.4295	-280	0.102991
20081103	VV	-71.5103	-245	0.105284
20081208	VV	169.4865	-210	0.101397
20090112	VV	-89.8353	-175	0.104775
20090216	VV	-97.8074	-140	0.211094
20090323	VV	-424.558	-105	0.10306
20090427	VV	-39.959	-70	0.101316
20090706 (Master)	**VV**	**0**	**0**	**0.106066**
20090810	VV	38.01472	35	0.105554
20090914	VV	-374.794	70	0.108081
20091019	VV	197.2853	105	0.104065
20091123	VV	-283.173	140	0.1065
20100201	VV	-348.454	210	0.106912
20100308	VV	91.97544	245	0.107895
20100412	VV	-169.311	280	0.111501
20100517	VV	-210.939	315	0.10175
20100621	VV	-63.034	350	0.113047
20100726	VV	227.5826	385	0.113062

Thresholding

Thresholding is used for the selecting the PS candidates (pixels having Persistent Scatterers) on basis of phase stability. Ferretti et al. (1999, 2000) introduced criterion of Amplitude Dispersion (D_A).

Amplitude Stability Index (ASI) has been used for thresholding which is calculated as follows where m_A and σ_A are respectively the mean and the standard deviation of the amplitude values:

$$ASI = 1 - D_A = 1 - \frac{\sigma_A}{m_A}$$

Thresholding value of ASI was selected as 0.65.After that topographic phase is removed using DEM and Atomospheric Phase Screen is estimated and removed.

Results

- After Sparse Point processing of PS we get 7953 points.
- Majority of points were showing negative velocity and displacement.
- Density of points were more near the town, villages and roads.
- The coherence of the area was not so good due to presence of vegetation and moisture.
- Slow moving landslides were also affecting many roads along the rim of the reservoir.

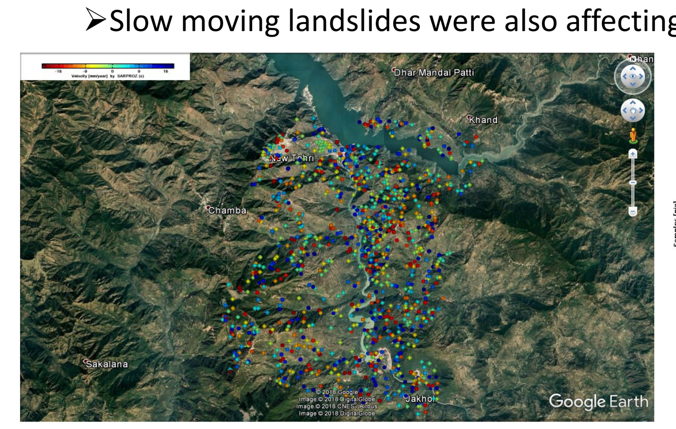

Figure 7. Time-Series Displacement of PS depicted on Google Earth

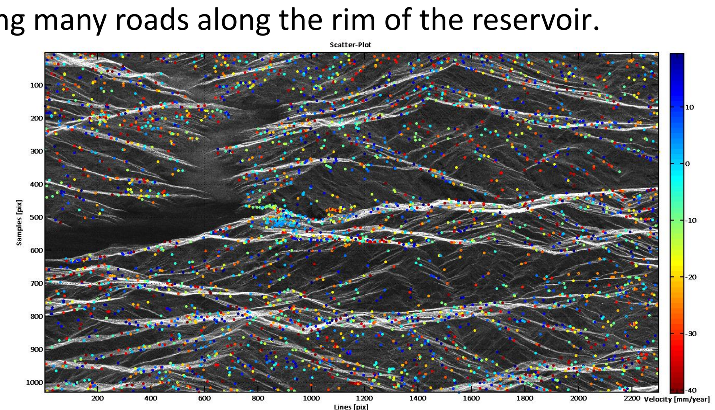

Figure 8. LoS velocity of PS in SAR coordinate system. Dark feature is the reservoir.

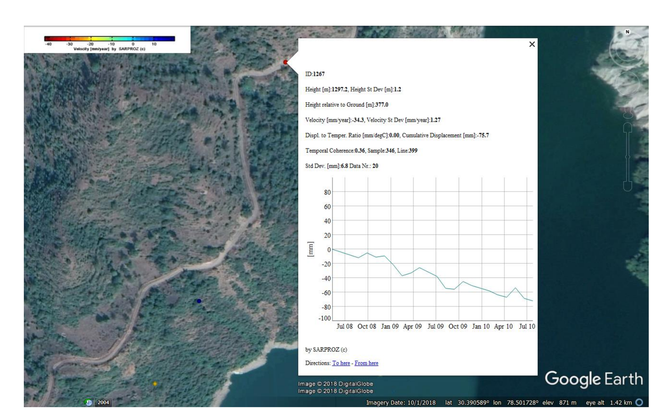

Fig. 9. Deformation Information of a PS on a road situated in the rim of the reservoir.

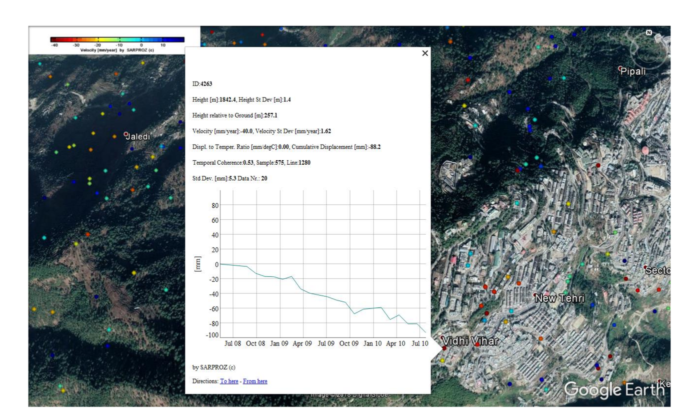

Fig. 9. Deformation Information of a PS in New Tehri town.

More Results

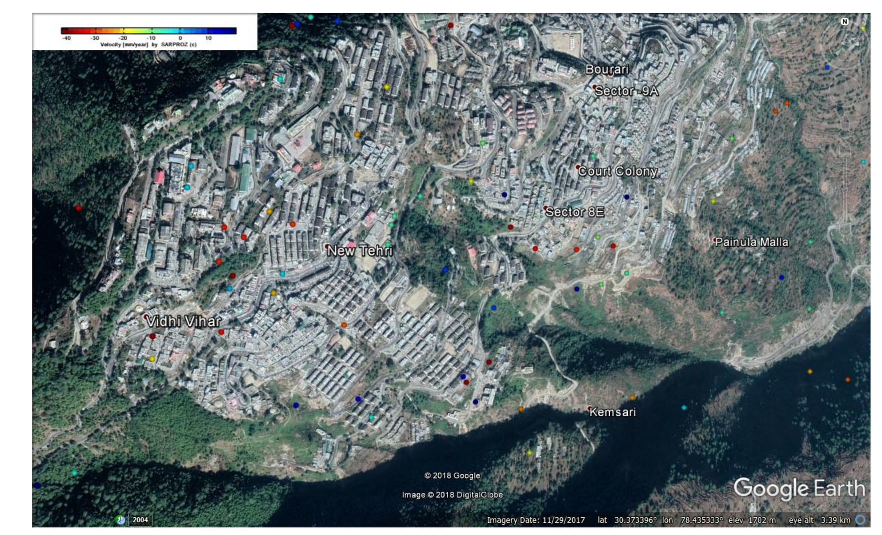

Figure 10. Presence of PS having negative velocity (LoS) in New Tehri township near Tehri Reservoir

The figure (10) shows concentration of PS in a town located near reservoir. All these points are at higher elevation are showing negative velocity as high as 40mm/year and points at lower elevation are showing lower positive velocities.

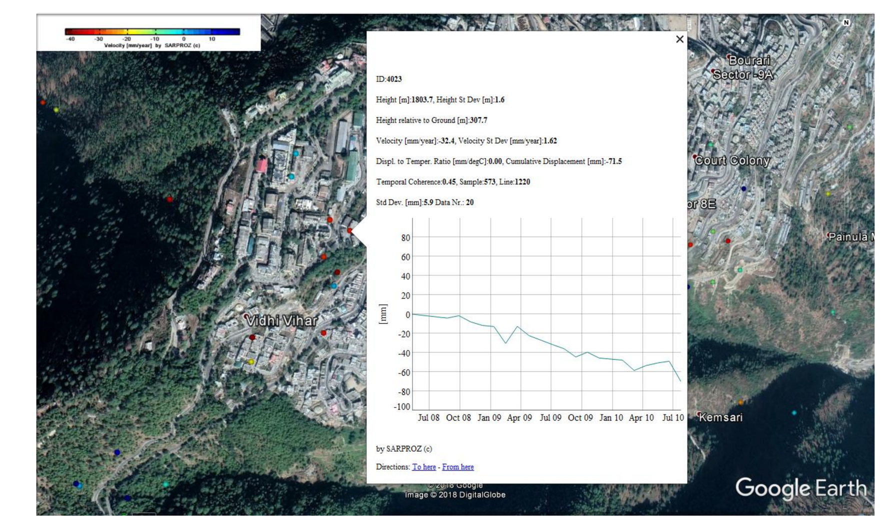

Fig. 12. Showing time series trend of displacement of a PS in Tehri township.

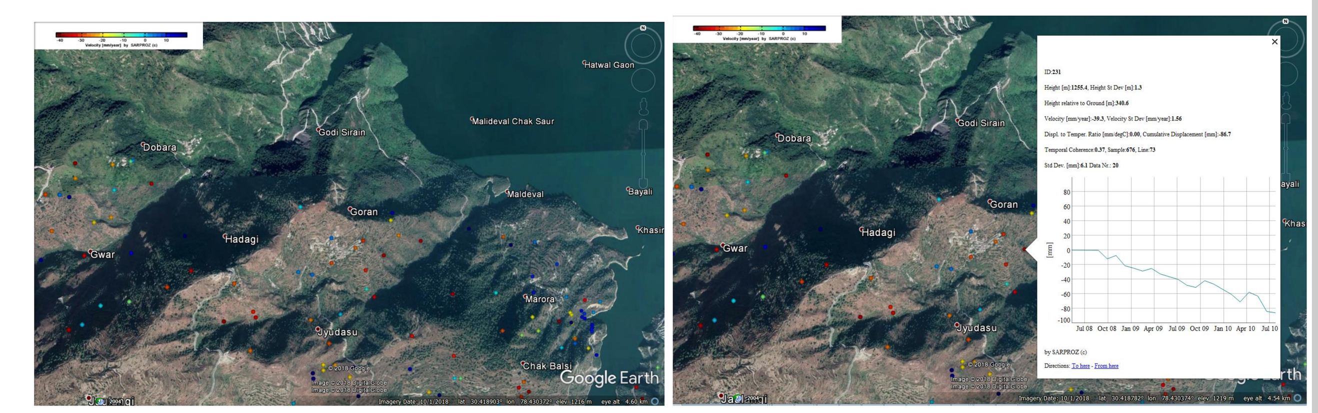

Fig. 13(a) (Right). PSs on rim of Tehri reservoir. 13 (b) (Left).Showing displacement trend of a PS in the area of 13(a)

Conclusions

- Some PS have been identified showing velocity of nearly 20 mm/year in the direction of line-of-sight. Most of them are situated near the reservoir.
- A cluster of high negative velocity (i.e. velocity away from the line of sight of sensor) is found in the New Tehri township which is situated around three kilometers away from the reservoir.

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